Adaptive Beamforming for SAR Ambiguity Rejection

Gerald Benitz
MIT Lincoln Laboratory
244 Wood Street
Lexington, MA 02420-9108
phone: 781-981-4665
email: benitz@ll.mit.edu

Abstract The Lincoln SPARTA program is developing next-generation phased arrays for enhanced radar performance and efficiency. One novel capability being explored is simultaneous operation of MTI (moving target indicator) and SAR (synthetic aperture radar) imaging, two functions that are usually mutually exclusive. MTI scans large areas quickly, using short integration (~10 msec) and low bandwidth (~10 MHz). SAR, in contrast, stares for seconds at each location and has high bandwidth (~600 MHz). Simultaneous operation requires multiple beams, frequency-division multiplexing, and synchronized pulsing. Also, MTI requires a higher PRF (pulse-repetition frequency) than SAR, and multiple PRFs for ambiguity resolution. Hence, it is desirable for SAR to function with MTI pulse scheduling.

This presentation explores the use of adaptive beamforming to extend SAR performance to unfavorable PRFs. A low PRF implies that Doppler-ambiguous clutter is near the main lobe, while a high PRF implies that range-ambiguous clutter is near the main lobe. An image-domain, minimum-variance beamformer is presented which attenuates ambiguous clutter, adapting the beam uniquely at each location (pixel) in the image. A simulated SAR collection at high PRF using a 3-beam combiner demonstrates a practical, limited degree-of-freedom implementation.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
20 DEC 2004	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Adaptive Beamforming for SAR Ambiguity Rejection	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **MIT Lincoln Laboratory 244 Wood Street Lexington, MA 02420-9108**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also, ADM001741 Proceedings of the Twelfth Annual Adaptive Sensor Array Processing Workshop, 16-18 March 2004 (ASAP-12, Volume 1)., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**24**	

Adaptive Beamforming for SAR Ambiguity Rejection

ASAP 2004

Gerald Benitz

17 March 2004

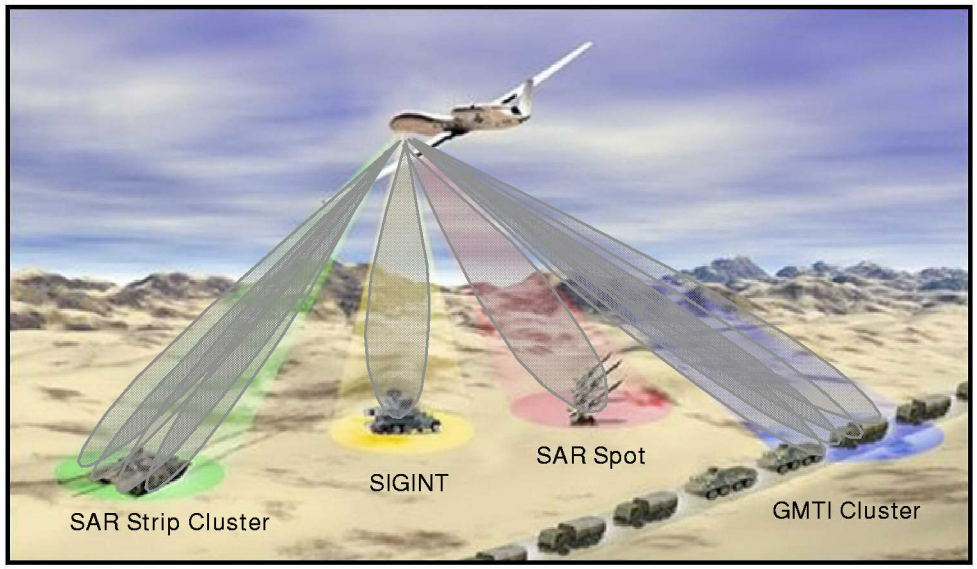
This work was sponsored by the Department of the Air Force under Contract F19628-00-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and not necessarily endorsed by the U.S. Government.

Outline

- Problem description
- High DOF solution
- Practical solution
- Summary

Space and Airborne Radar Transformational Arrays (SPARTA)

Multi-Beam/ Multi-Mode System

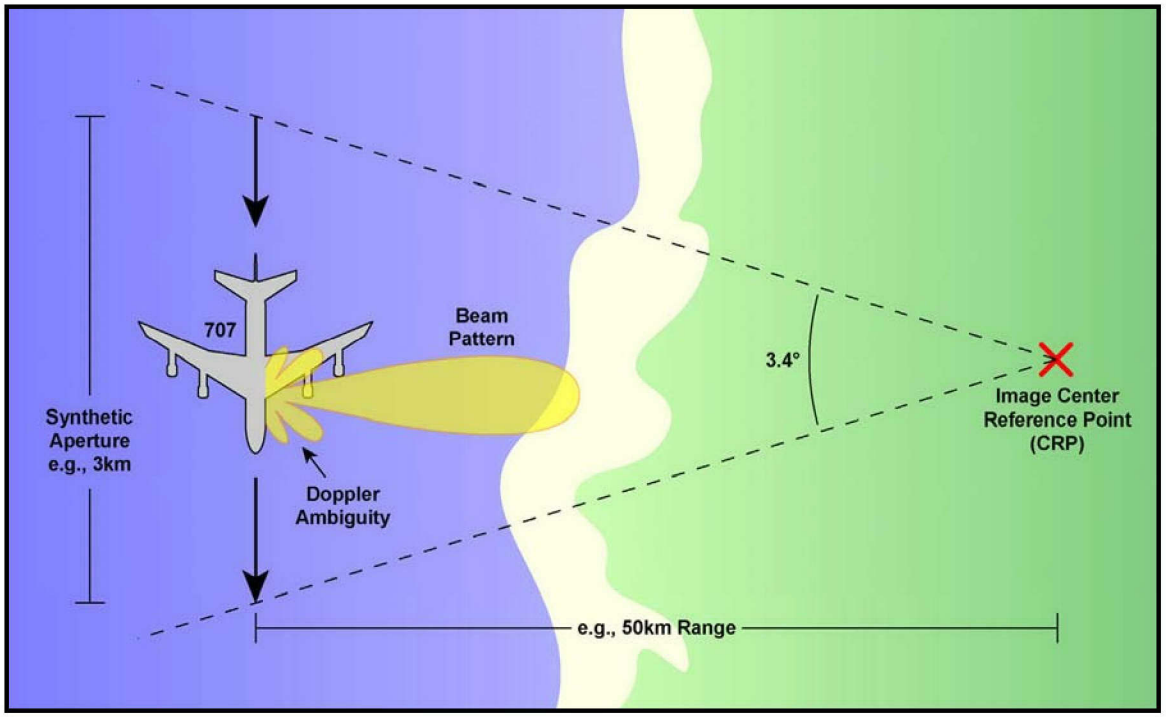


Key Attributes:

- Multifunction sensor capabilities
  - Concurrent GMTI, SAR, SIGINT
  - Cradle-to-grave tracking
- Challenge: Agile array and advanced signal-processing techniques

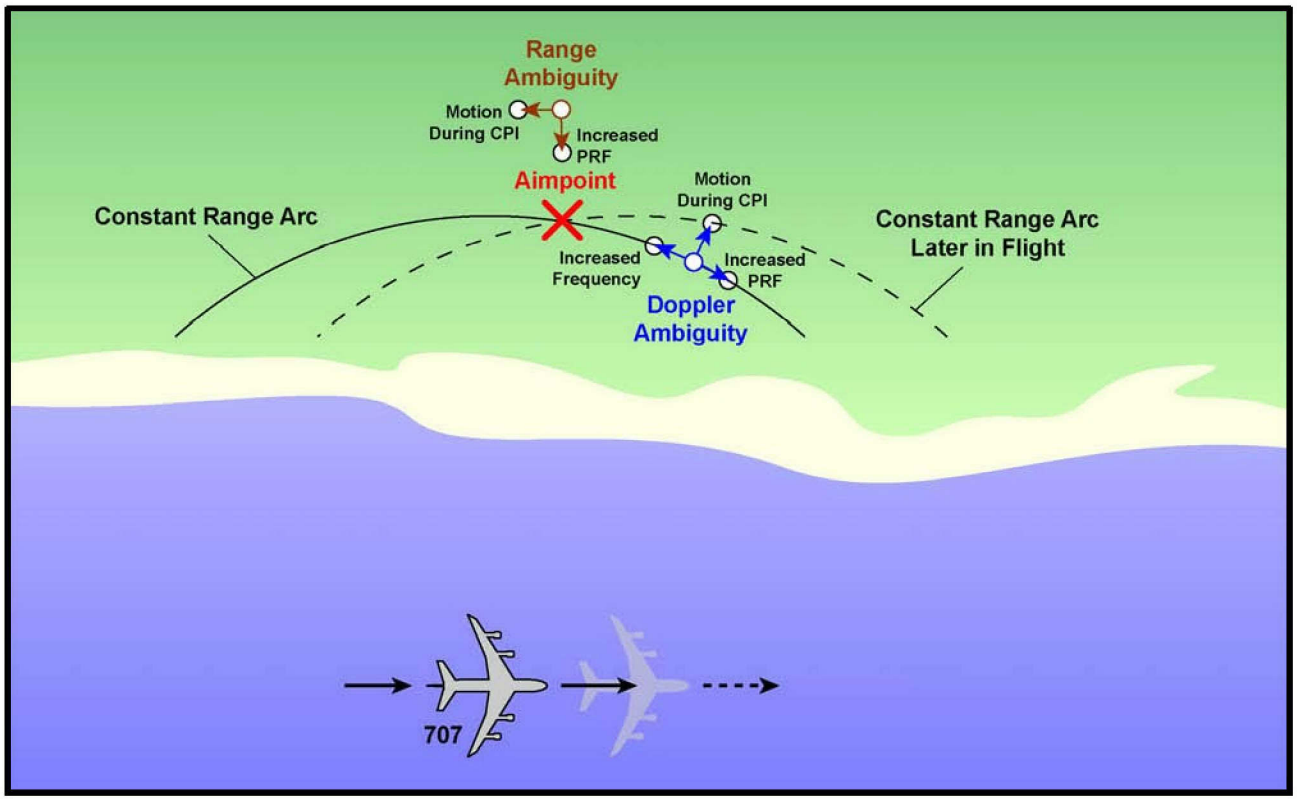
1-ft Resolution X-Band SAR

- Requires 600-MHz bandwidth and 3.4° viewing angle
  - 3-km aperture @ 50-km range, 16-sec CPI @ 180 m/s
- Ambiguity sidelobes ≤ –27 dB 2-way (rule of thumb)
  - Desire signal-to-interference ratio (SIR) > 20 dB
- Image formation costs about 2000 ops per pixel
  - Polar-format method followed by autofocus



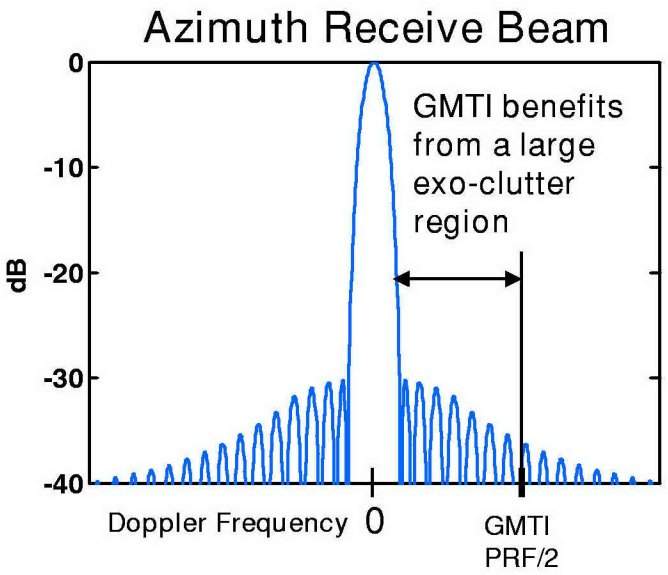
Ambiguity Rejection

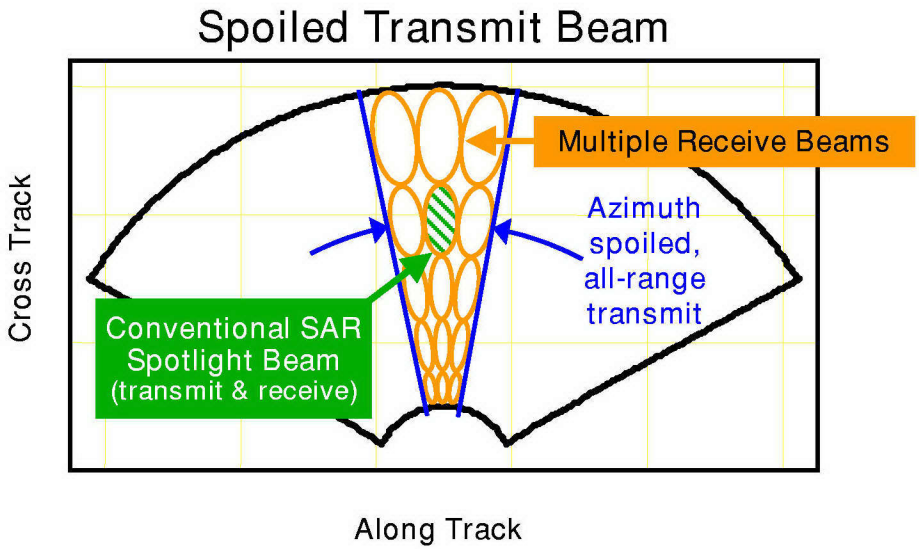
- In conventional SAR, the PRF is chosen to keep range and Doppler ambiguities out of the main lobe
- Adaptive beam SAR must address nonstationary ambiguities
  - Locations change with frequency and time
  - Corollary: Ambiguous clutter discretes get highly blurred



Simultaneous SAR and GMTI

- GMTI selects the PRF
  - Determines unambiguous velocity
  - Maintains exo-clutter region
- Spoiled transmit improves area rate
  - All-range strip mode
  - Large area spotlight



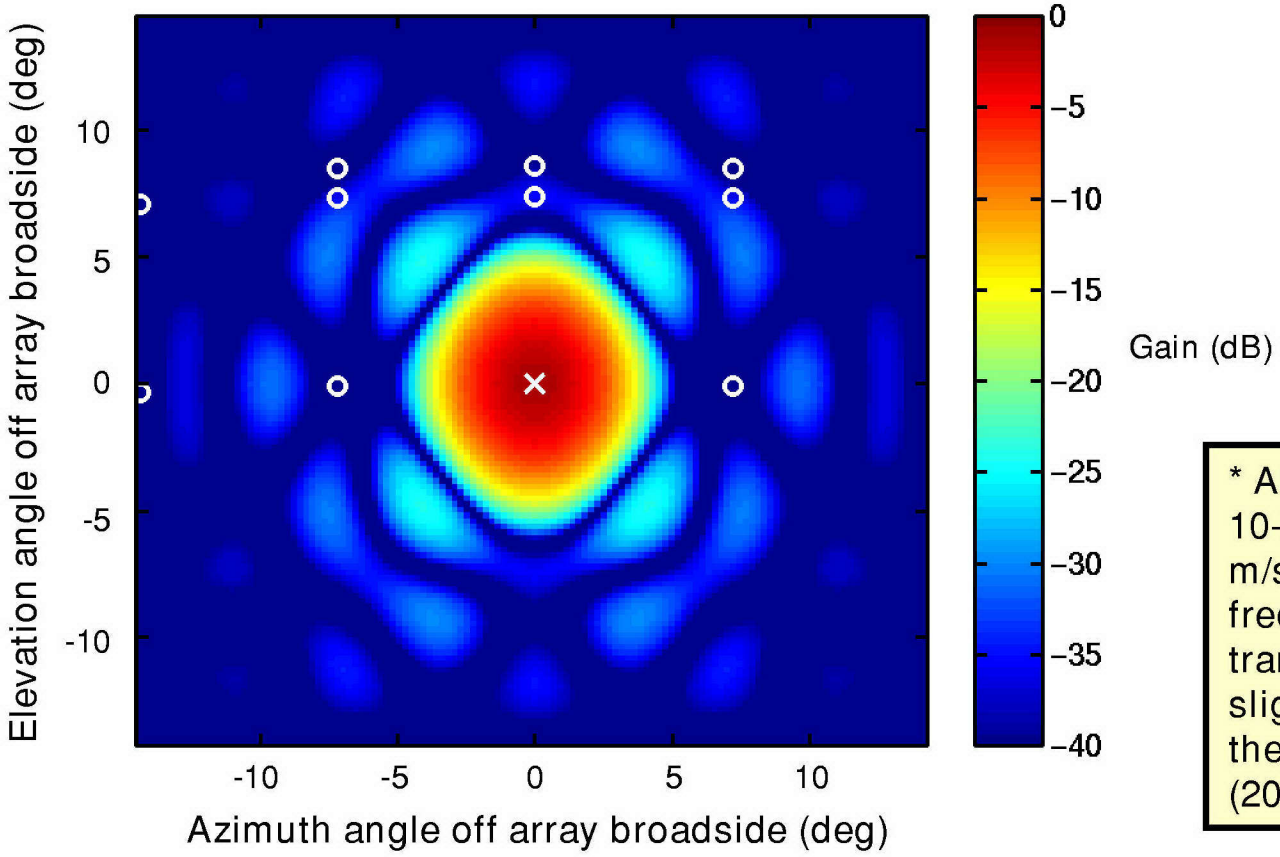


Outline

- Problem description
- High DOF solution
- Practical solution
- Summary

Conventional SAR Beam Pattern

- Collection parameters*: 50-km range, 1500-Hz PRF
- Tapered beam (30 dB Taylor) achieves 46-dB SIR

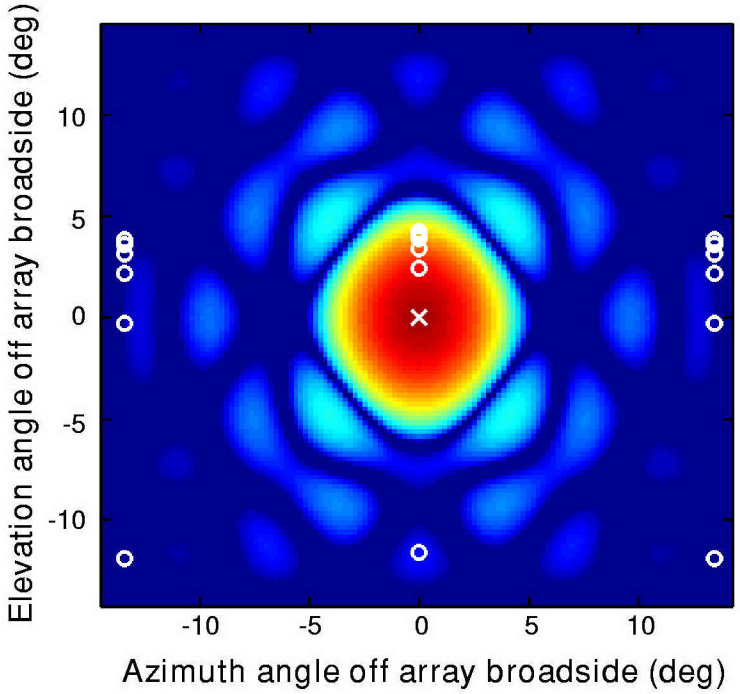


* All results assume 10-km altitude, 180 m/s, 10-GHz center frequency, and a transmit pattern slightly wider than the subarray pattern (20 deg)

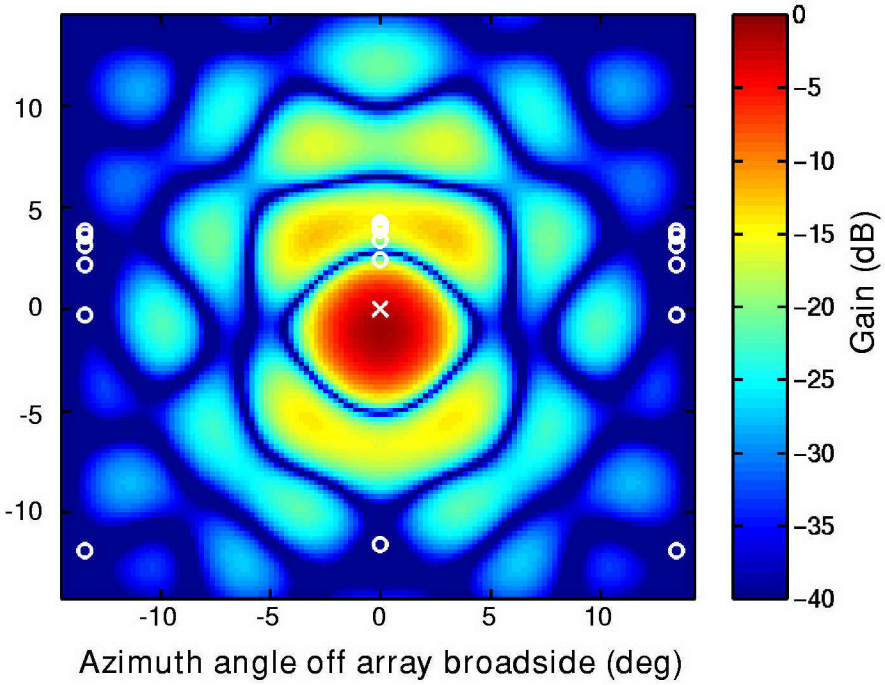
Adaptive Beam Comparison

85-km Range, 2800-Hz PRF

- Taylor taper
- 11-dB SIR @ 0.8-dB SNR loss



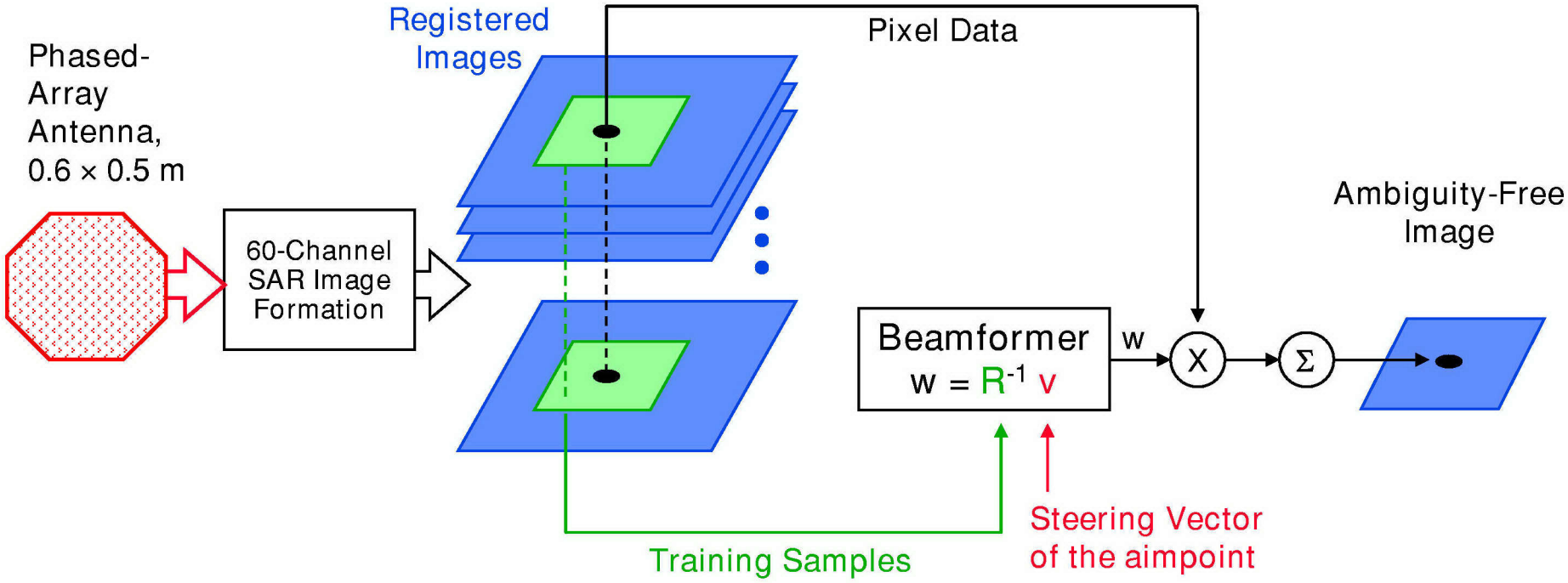
- Adaptive beam
- 24.8-dB SIR @ 1.5-dB SNR loss



- Beamformer assumes 20-dB CNR

Fully Adaptive SAR Approach

- Form 60 SAR images, one for each phase center
- Adapt on a pixel-by-pixel basis
  - A 60 degree-of-freedom, minimum-variance beamformer
  - Ample training samples come from high resolution
  - Main-beam nulling is avoided by calibration, covariance conditioning, and/or noise loading



Why an Image Domain Beamformer?

- Simple design
- Null locations naturally track pixel locations
- Minimal distortion of the SAR image
- Ample training samples
  - 100 m^2 gives 1000 looks at 1-ft resolution
- Potential for weight vector reuse

Simulation of the Ambiguity Covariance

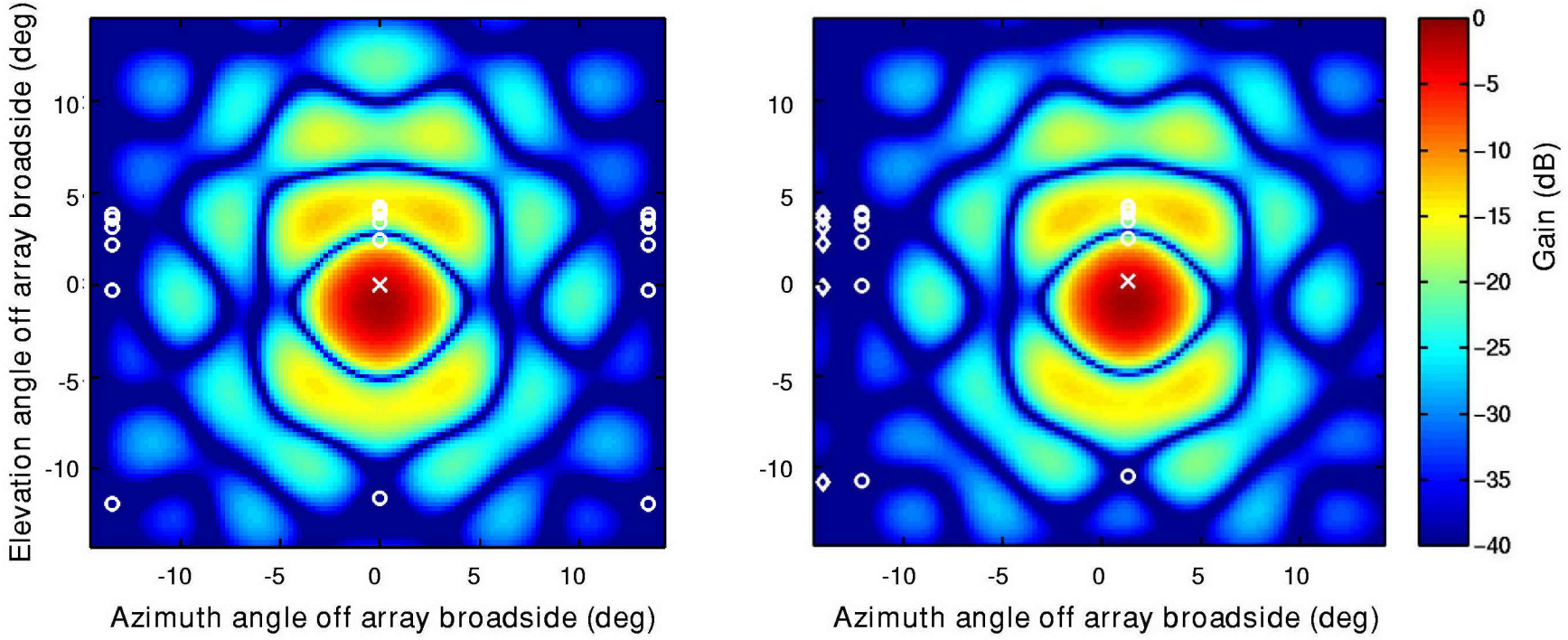
- Choose a point in the image (pixel location)
- Compute the ambiguity locations and relative sigma-0 as a function of frequency and time
- Generate CRP-adjusted steering vectors for the ambiguities over frequency and time
- Generate single-look covariance matrices at the ambiguities weighted by the relative sigma-0
- Integrate into one covariance matrix

Beam Variation over the Image

85-km Range, 2800-Hz PRF

- Beam is tuned for CRP
- 24.8-dB SIR @ 1.5-dB SNR loss

- Beam at 2-km range, 2-km cross range
- 24.5-dB SIR @ 1.6-dB SNR loss
- Shifted CRP beam provides 21.1-dB SIR @ 1.5-dB SNR loss



Weight vector reuse improves computational efficiency.

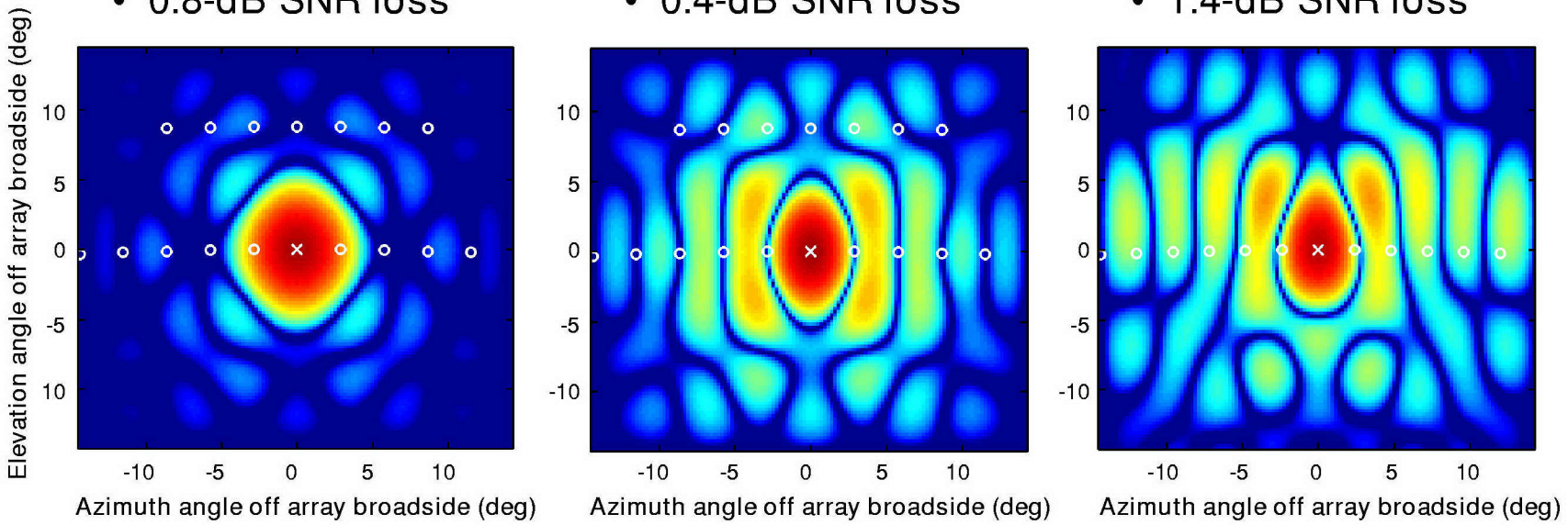
Beam Comparison at Low PRF

50-km Range

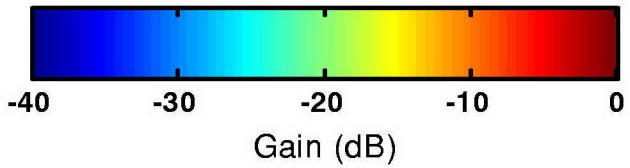
- Taylor taper
- 600-Hz PRF
- 5.3-dB SIR
- 0.8-dB SNR loss

- Adaptive beam
- 600-Hz PRF
- 47.6-dB SIR
- 0.4-dB SNR loss

- Adaptive beam
- 500-Hz PRF
- 7.9-dB SIR
- 1.4-dB SNR loss



Symmetric Doppler ambiguities are difficult to cancel.



Outline

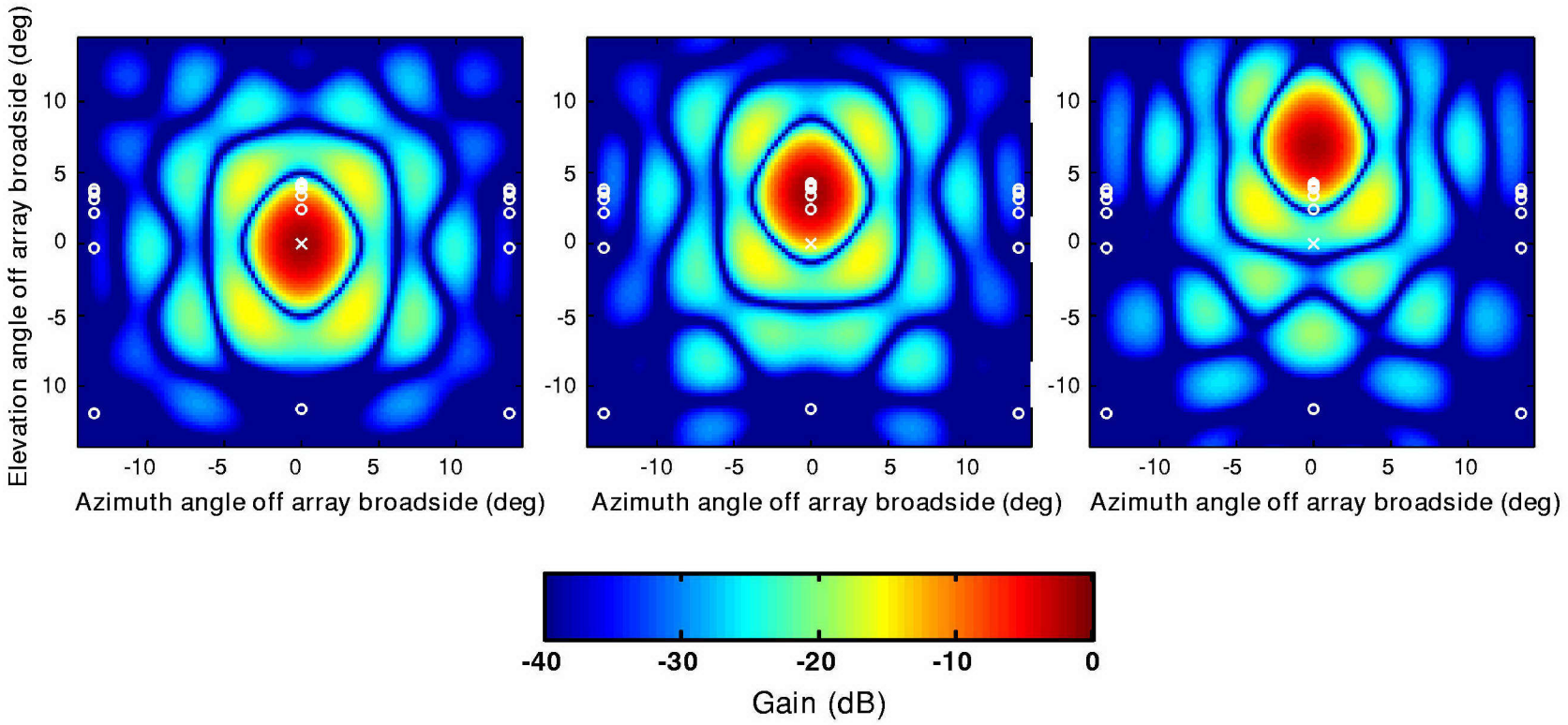
- Problem description
- High DOF solution
- Practical solution
- Summary

Practical Issues and Solutions

- Computational limits prohibit 60-channel SAR
  - Solution: Use 2 or 3 beams focused on close-in ambiguities
  - Drawback: Limits area rate
- Array errors
  - Adaptive beamforming should track errors
  - Steering errors may require noise-gain constraints
- Optimizing SIR rather than SINR
  - SINR benefits detection but not necessarily image quality
  - Options: Power-selective training, diagonal "unloading"

Example: Beams for High PRF Case

- Beams are chosen at CRP and 1 and 2 beamwidths above
  - an arbitrary choice
- Sidelobes are chosen to cancel far-removed ambiguities



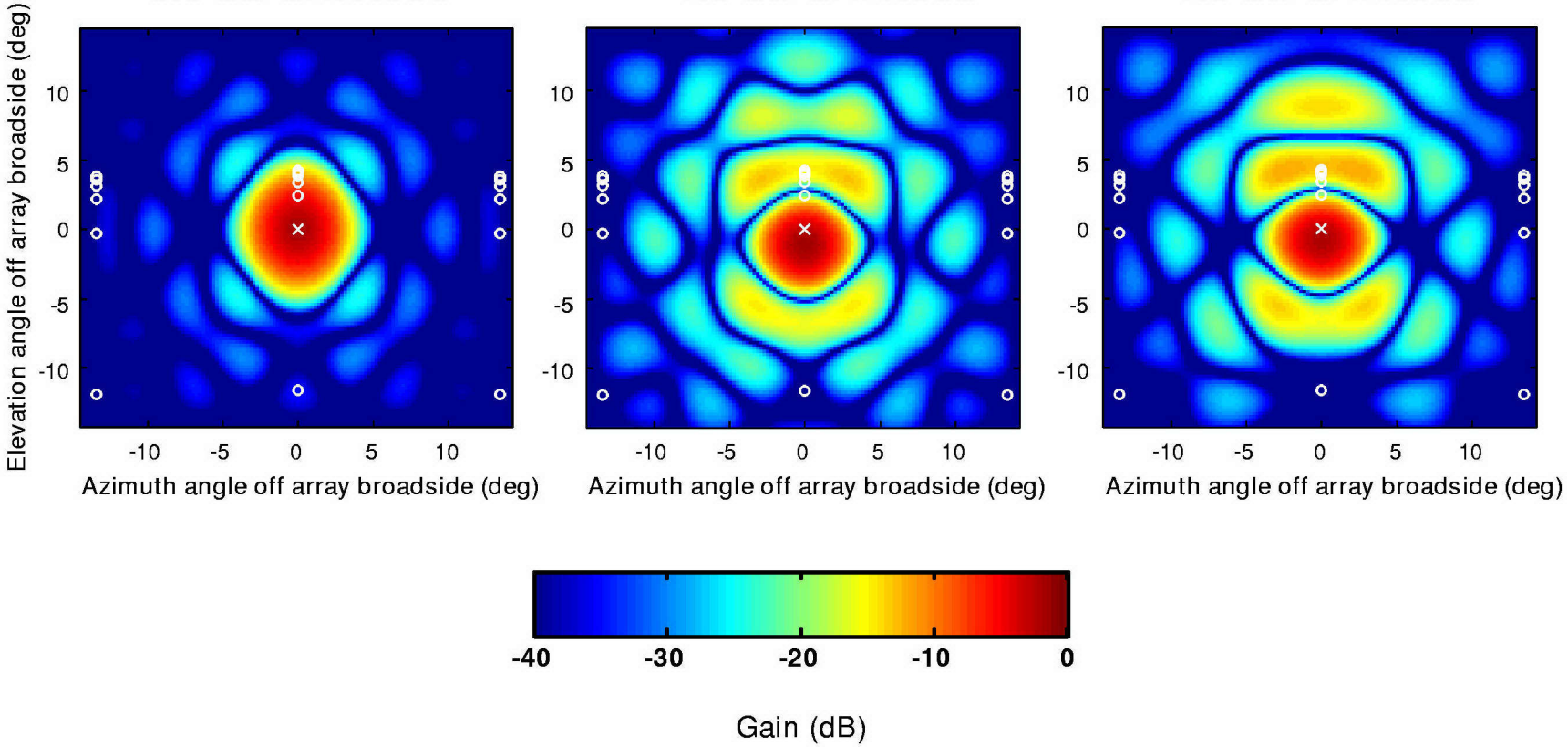
Fully Adaptive vs 3 Beams

85-km Range, 2800-Hz PRF

- Taylor taper
- 11-dB SIR
- 0.8-dB SNR loss

- 60-channel
- 24.8-dB SIR
- 1.5-dB SNR loss

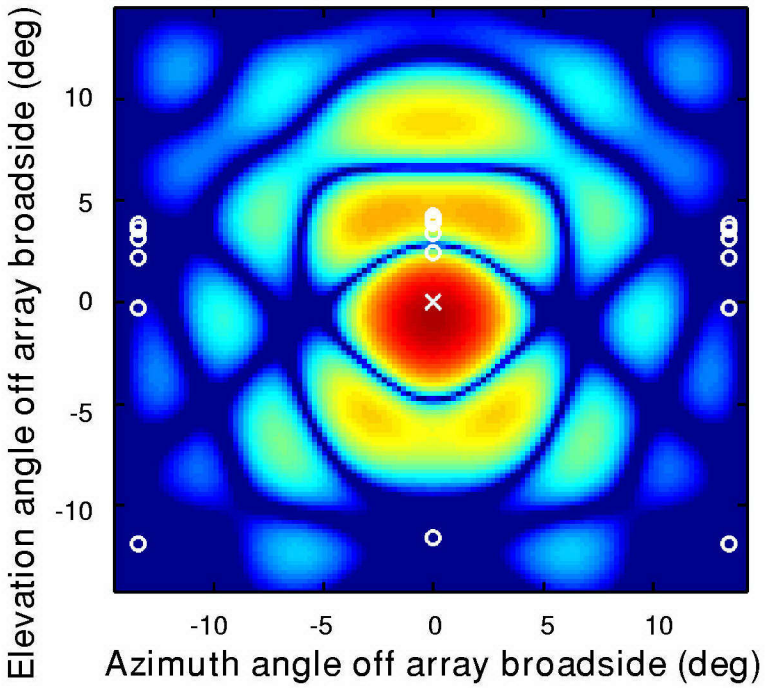
- 3-beam
- 22.9-dB SIR
- 1.5-dB SNR loss



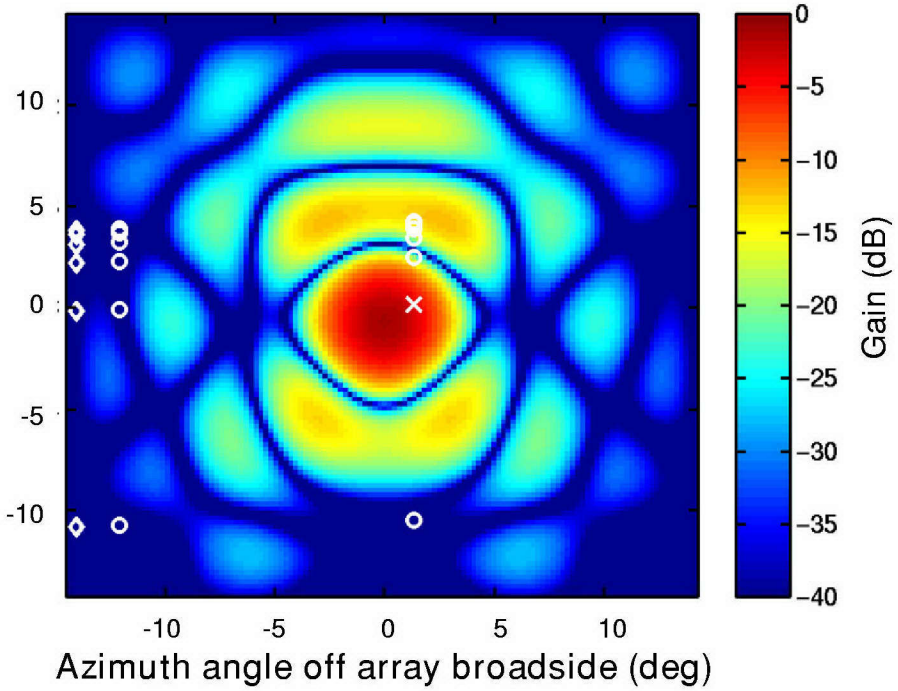
Beam Comparison at Image Offset

85-km Range, 2800-Hz PRF

- 3 *a priori* beams
- Aimpoint: broadside
- 22.9-dB SIR @ 1.5-dB SNR loss



- 3 *a priori* beams
- Aimpoint: 2-km range, 2-km cross range
- 21.8-dB SIR @ 3.2-dB SNR loss



- SNR loss is scalloping loss
- Additional beams increase area and reduce losses

Verification: A SAR Image Test

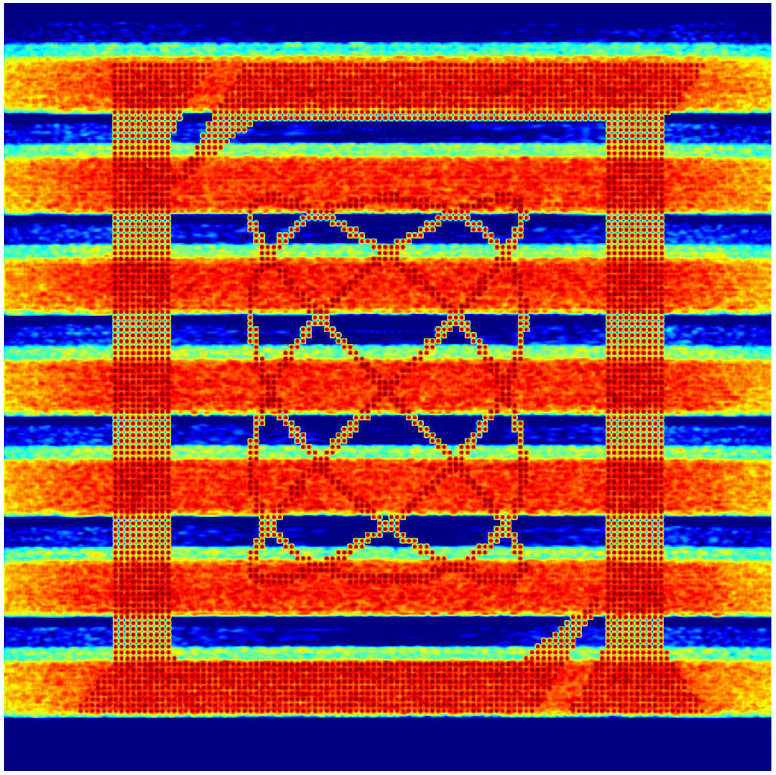
- Generate clutter at the CRP and at the closest range ambiguity, 0.7 elevation beamwidths away
  - Approximately 5000 clutter points over a 300 m × 300 m patch at each location
- Generate true time-delayed returns at all 60 phase centers over a 29 sec CPI
  - Emulates actual steering vector dispersion
- Form 3 *a priori* beams
- Form 1-ft resolution SAR images for each beam separately
  - Use polar-format method
- Apply adaptive beams derived from covariance analysis

Adaptive SAR Simulation Results

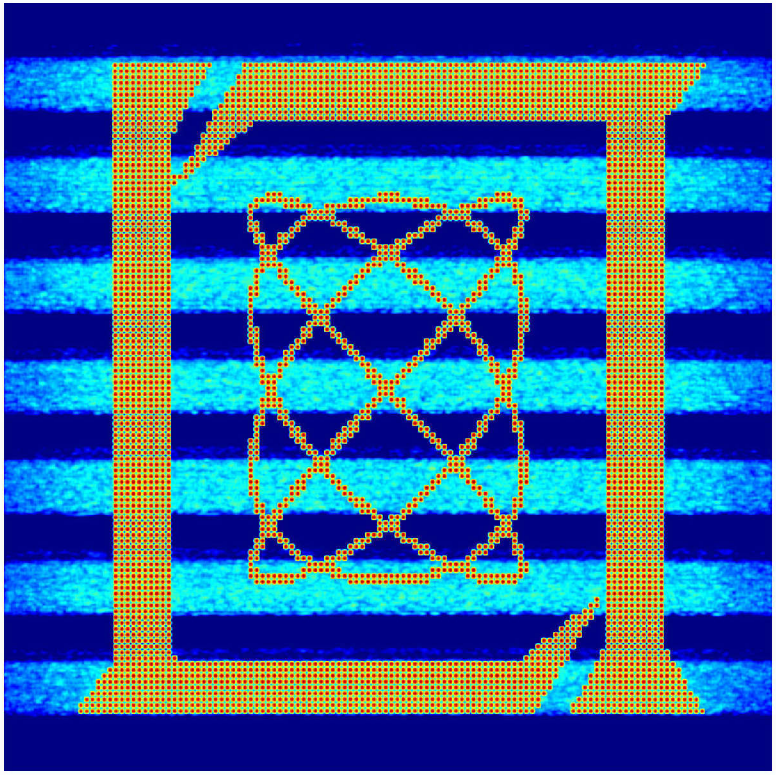
85-km Range, 2800-Hz PRF

- Images are 350 m × 350 m, near range at the top
- Display is normalized to noise floor, but noise is excluded

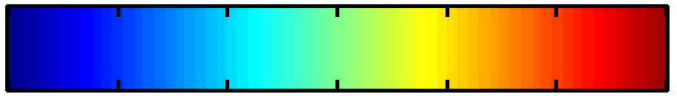
Main Beam Only



2 Beams: 13-dB SIR, –1-dB SNR (rel)



Note: Ambiguous clutter is exaggerated 6 dB above expected level

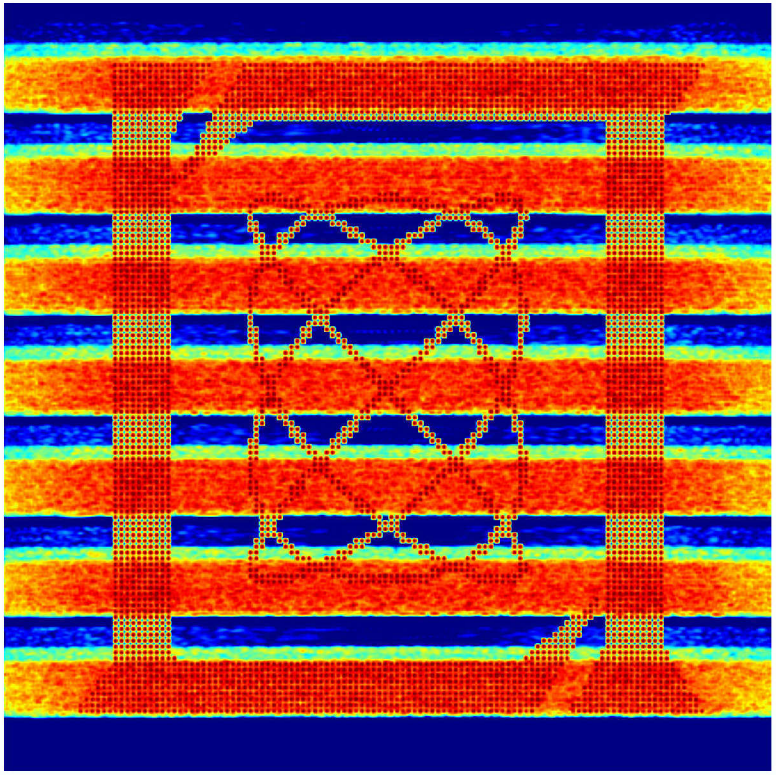


Adaptive SAR Simulation Results

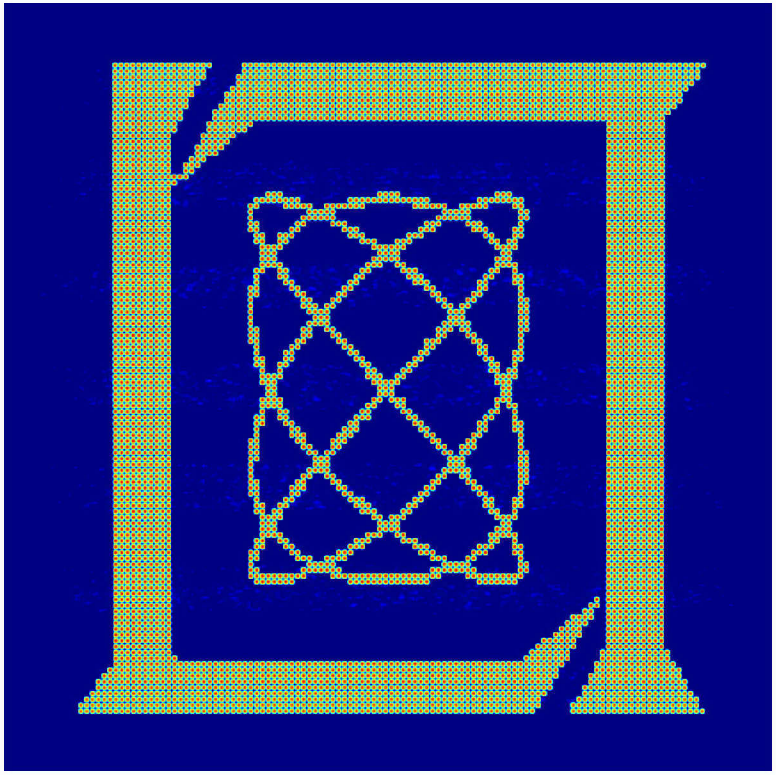
85-km Range, 2800-Hz PRF

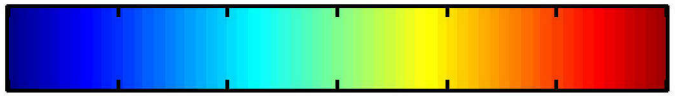
- Images are 350 m × 350 m, near range at the top
- Display is normalized to noise floor, but noise is excluded

Main Beam Only



3 Beams: 21-dB SIR, –4-dB SNR (rel)





Summary

- A concept for using adaptive beamforming to enable SAR in a multi-mode radar has been simulated
  - addresses GMTI-driven PRFs and spoiled transmit beams
- Slowly varying weights and high resolution imply easy training and low image distortion
- A 3-beam cluster promises to provide ample protection in a high-PRF scenario
  - Multiple clusters enable wide-area contiguous ground coverage